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Effects of size grading on growth and survival of juvenile turbot at two temperatures

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Juvenile turbot were size graded into three size groups (mean initial size): Small (3.4 g), medium (7.0 g) and large (10.5 g), and additional fish were held in ungraded (6.6 g) groups. Subgroups (n = 396) of fish were tagged and individual growth rates and social interactions within different size categories were studied in fish reared at 13 and 19 °C. Size grading of juvenile turbot did not improve growth. Specific growth rates (*SGR*) were mainly size-related, and no differences in *SGR* or mortality between the experimental groups at both temperatures were found. A higher level of social interactions was indicated amongst medium-sized fish than amongst those in the smallest and largest categories. Excess feeding may have been important factors in reducing aggression, so that the growth of the smallest individuals was not suppressed by the larger individuals in the present study. Grading seems to be an unnecessary operation to improve the growth and survival of juvenile turbot (5–150 g). However, as it was mainly the smallest individuals in each group that died, grading of very small turbot (2–5 g) can be recommended.

KEYWORDS: Grading, Growth, Survival, Turbot (*Scophthalmus maximus*)

INTRODUCTION

Farming of flatfish species, e.g. turbot, *Scophthalmus maximus*, and Atlantic halibut, *Hippoglossus hippoglossus* has received considerable interest in Europe over the past two decades. Production of turbot increased from 4 metric tonnes (t) in 1984 to 3000 t in 1995 (H. Josupeit, Fishery Industry Division, FAO, Rome, unpublished data), and the production of Atlantic halibut is increasing rapidly, especially in Norway (Pittman *et al.*, 1995). As flatfish farming increases, there will be greater emphasis on optimization of production, because these species are, as a consequence of their morphology and behaviour, area demanding in culture (Cripps and Poxton, 1992; Björnsson, 1994).

One of the main aims in finfish aquaculture production is to maximize biomass yield with lowest possible input (Purdom, 1974), and to achieve this sufficient resources must be made available for all individuals. Size grading is used in the

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culture of many commercial fish species in an attempt to improve growth and survival (Gunnes, 1976; Huet, 1986; Baardvik and Jobling, 1990; Popper *et al.*, 1992; Kamstra, 1993). The main idea behind size grading is to separate small and large individuals from each other to avoid potentially negative effects of social interactions (Jobling, 1982, 1995; Knights, 1987). In some fish species, dominant individuals exhibit higher growth rates than subordinates (Brown, 1946; Magnuson, 1962; Jobling, 1985, 1995; Koebele, 1985), and several mechanisms have been proposed to explain how larger dominant individuals suppress the growth of small subordinates (Wirtz, 1974; Koebele, 1985; Wallace *et al.*, 1988). Competition for food seems to be particularly important in governing growth (Magnuson, 1962; Wallace and Kolbeinshavn, 1988; Jobling and Koskela, 1996), and in the absence of competition from larger individuals, smaller individuals avoid the negative effects of a dominance hierarchy and may achieve higher growth rates (Purdom, 1974). However, in some cases size grading has been shown to reduce growth, possibly owing to higher levels of interaction between fish of the same size (Doyle and Talbot, 1986; Baardvik and Jobling, 1990).

Size grading is in itself a stressful procedure for fish (Pickering, 1981) although there are species differences in stress tolerance (Davis and Parker, 1990; Waring *et al.*, 1992), and Waring *et al.* (1996) showed that turbot were fundamentally different from salmonids in that plasma glucose concentrations in turbot are refractory to handling stress. However, size grading is labour-intensive and mechanical size-graders for flatfish are not commercially available, although a prototype grading device has been developed in France (Person-Le Ruyet *et al.*, 1991): Thus the costs of size grading can be high, especially if one also takes into consideration the risk of handling damage, disease outbreak and growth reduction. At present there are no clear guidelines about the need, or frequency, for grading in turbot culture, but Person-Le Ruyet *et al.* (1991) advise size grading at least once or twice during the ongrowing phase (2–150 g).

The following experiment was designed to investigate the effect of size grading on growth and survival of juvenile turbot reared at two temperatures (13 and 19 °C). A group of turbot (offspring from one female and two males) was size graded into three size groups: Small, medium and large, and additional fish were raised as an ungraded group. A subgroup of fish was tagged and individual growth and social interactions within the different size classes studied.

MATERIALS AND METHODS

Experimental fish and rearing conditions

Eggs from one female turbot and sperm from two males were pooled, and incubation of fertilized eggs started on 7 July 1991. After hatching, the larvae were transferred to 8 m^3 plastic bags floating in a seawater basin (at Selvåg just south of Bergen, Norway), in which the temperature was approximately 18 °C. Starting on 16 July, the larvae were fed natural zooplankton filtered from the basin. After metamorphosis the juveniles were transferred to rearing tanks (1000 l) containing water at 13–16 °C, and the fish were fed a commercial dry diet. In October the juveniles were brought to the Industrial Laboratory at the Bergen High Technology Centre where they were held at 13 °C. The fish were reared under simulated natural light regime for Bergen (60°25'N), from first feeding until the termination of the experiment. The fish used originated from a group of 2800 juvenile turbot of which 1583 were used in this study. At the beginning of the experiment the fish had a mean (SD) weight of 6.9 (1.6) g.

The study was carried out from 8 November 1991 to 27 March 1992 using 1 m^2 square (with rounded corners), grey, covered fibreglass tanks with a rearing volume of 400 l. Seawater with a salinity of 34.5 ± 0.2‰ was pumped from 90 m depth and water flow was initially set at 20 l min^{-1} per tank. The oxygen concentration was always kept above 6.5 mg O_2 l^{-1}. All groups of fish were fed commercial dry feed (Marin pellets 2–4 mm; Felleskjøpet AS, Bergen) in excess using automatic feeders timed to deliver feed every 6 min during the photophase. Amounts fed were adjusted after each weighing based on previous growth rates and the biomass in each tank. Light was provided by one 36 W fluorescent daylight tube installed in the tank cover. Photoirradiance at the tank bottom was approximately 4.24 $\mu E\ m^{-2}\ s^{-1}$. A computer program (LYSSTYR 2.00, Hansen, 1990) generated a simulated natural light regime including twilight periods.

Experimental design

On 8 November the fish were weighed, manually graded into three groups (mean (SD) weights): Small 3.4 (0.9) g, medium 7.0 (1.7) g, large 10.5 (1.4) g and an additional control group of ungraded fish 6.6 (2.6) g was maintained. The fish were then distributed among 16 tanks (n = 90–100 fish in each tank). Two temperature regimes were established: 13 °C and 19 °C, to give eight experimental groups, each being replicated. The temperature of 19 °C was attained within 5 days of establishing the different experimental groups.

Individual tagging and size categories

On 17 January (19 °C) and 31 January (13 °C) 396 randomly chosen fish were tagged intraperitoneally with Fisheagle® PIT tags (Prentice *et al.*, 1986). Owing to a limited number of tags, fish from only one replicate tank (n = 39–40) in each of the small, medium and large groups were tagged. Fish from both replicates of the ungraded group were tagged (n = 79–80). No fish died during tagging and no tags were lost during the experiment.

Tagged fish in each tank were size ranked on the date of tagging and using this ranking the tagged fish in each tank were categorized as belonging to one of four size categories with 9–10 individuals in each: A (smallest), B, C, D (largest).

Data analysis and statistical methods

All fish were weighed individually to the nearest 0.01 g every 2 weeks. Specific growth rate (*SGR*) was calculated according to the equation of Houde and Schekter (1981):

$$SGR = (e^{g} - 1)*100 \tag{1}$$

where $g = (\ln W_2 - \ln W_1)\ (t_2 - t_1)^{-1}$ and W is wet weight (g) on days t_2 and t_1, respectively. *SGR* was regressed against geometric mean weight, $GM = (W_1 * W_2)^{1/2}$ in the given time interval. To avoid the risk of pseudoreplication, data for tagged fish in each tank were combined. The growth rates during the first 2 weeks after tagging were not included in this analysis.

All statistical analyses were performed with STATISTICA™ 4.1 (StatSoft, 1994). A Kolmogorov–Smirnov test was used to assess normality of distributions (Zar, 1984), and homogeneity of variances was tested using Levene's *F*-test (Brown and Forsythe, 1974). A three-way nested Model III ANOVA (Scheffé, 1959) was applied to calculate the effect of grading and temperature on weight at respective time periods with replicates being nested within grading groups and temperature. Significant ANOVAs were followed by a Student–Newman–Keuls multiple comparison test to determine differences among experimental groups. Individual growth trajectories were analysed using a growth curve analysis model (GCM) (Timm, 1980; Chambers and Miller, 1995), which is an extension of the multivariate repeated measurements analysis of variance (MANOVA) model. The *SGR* versus *GM* regressions were analysed using covariance analysis (ANCOVA, Sokal and Rohlf, 1995). Size ranking (initial size rank versus final size rank) of the fish within the four size categories (A, B, C and D) was tested using Spearman's rank (r_S) correlation (Zar, 1984), and the r_S from each group tested for significance in a *t*-test (Zar, 1984). The analyses were carried out for all size categories combined (ABCD), for medium-size fish combined (BC), and for large (D) and small (A) fish. The r_S correlations for BC and AD were tested for equality with a *Z*-test (Rao, 1973; Zar, 1984). Separate analyses were done for each temperature. Coefficient of variation of weight, CV = 100 * (SD / mean weight), for each replicate tank of the grading groups was regressed against weight and analysed with log regression ($Y = A_0 + A_1 \log(X)$), where A_0 and A_1 are constants, Y is CV and X is wet weight (Zar, 1984). Separate regressions were made for each temperature. Proportions of dead fish from each experimental group were $\sin^{-1}$ transformed (Zar, 1984) and tested with a two-way ANOVA (Zar, 1984).

RESULTS

Mortality

A total of 46 fish (2.9%) died during the experiment (Table 1). In December a bacterial infection, *Aeromonas* sp. (Roberts, 1993) was detected (O.M. Rødseth,

TABLE 1. Survival of four size-graded groups of juvenile turbot reared at two temperatures. Values for two replicates in each group are combined. Mean values for each grading and temperature group are given in addition to mean total survival of all experimental groups

Grading group	Size range (g)	Survival (%) 13 °C	19 °C	Mean
Small	3 – 95	92.4	95.5	94.0
Mean	7 – 120	98.5	98.5	98.5
Large	7 – 120	99.0	97.5	98.3
Ungraded	11 – 150	95.9	98.5	97.2
Mean survival		96.5	97.5	
Total survival				97.0

Institute of Marine Research, Bergen, pers. comm.), and oral antibiotic treatment (*Flumequine*; 30 mg kg^{-1} day^{-1}, was given from 13 to 18 December. Of the 46 mortalities, 27 were removed from the experimental tanks during the infection. These fish were nearly always below the mean weight of the respective tank. No differences in mortality were found between the experimental groups (two-way ANOVA, $p > 0.15$, Table 1), although the small fish had the lowest survival (not significant) at both temperatures (Table 1).

Growth

There were no significant differences in initial mean weights among the four tanks within each grading group (three-way nested ANOVA, $p > 0.20$, Fig. 1). Growth patterns tended to be similar, although weight increase was much greater at 19 °C than at 13 °C (Fig. 1). At each temperature the ungraded and the medium groups showed similar growth patterns. The mean weights of the ungraded and the medium groups at 19 °C were never significantly different throughout the experimental period (Student–Newman–Keuls test, $p > 0.10$, Fig. 1A), whereas in four cases significant differences were found between these groups at 13 °C (Student–Newman–Keuls test, $p > 0.05$, Fig. 1A). Similar trends were observed when pooled data from the three graded groups were compared with mean weights of ungraded groups (Fig. 1B).

The GCM analysis revealed growth-at-age (tagged fish) differences between the graded groups at both temperatures. Individual growth-at-age trajectories at 13 °C were different (MANOVA, Wilk's lambda $(\lambda)_{12, 508} = 0.57$, $p < 0.01$) among the four (small, medium, large, ungraded) groups from early February onwards. At 19 °C the groups had different growth-at-age trajectories from mid-January onwards (MANOVA, Wilk's $\lambda_{15, 522} = 0.73$, $p < 0.01$). At both temperatures the small fish had the highest average growth rates (1.48% day^{-1}, 1.50% day^{-1} for 13 °C and 19 °C, respectively) and the largest fish the lowest growth rate (1.14% day^{-1}, 1.41% day^{-1}). Similarly growth rates in all groups at both temperatures were highest at the start of the experiment and decreased with time as the fish increased in size (Fig. 2). At 13 °C, *SGR* decreased significantly with increasing size in the small and medium grading groups (linear regression, p 0.05, Fig. 2A and B). Growth rate also declined with size in the large and ungraded groups of fish at 13 °C although the regressions were not significant ($p > 0.05$, Fig. 2C and D). At 19 °C the decrease in *SGR* with size was highly significant in all groups (linear regression, $p < 0.01$, Fig. 2E–H). The regression lines for the four grading groups were parallel (ANCOVA, Table 2) at both temperatures, and the *SGR* was highly correlated with size (ANCOVA, $p < 0.01$, Table 2). Using size (*GM*) as the covariate, there were not found to be significant differences in *SGR* among the groups held at either 13 °C (ANCOVA, $p < 0.80$) or at 19 °C (ANCOVA, $p < 0.90$). Thus, common regressions could be calculated for each temperature, the line for 13 °C being (SE):

SGR (% day^{-1}) = 2.27(0.19) − 0.29(0.06)*lnGM (g) ($n = 72$, $t = -4.31$, $p < 0.001$, $r^2 = 0.22$)

and that for 19 °C groups being (SE):

SGR (% day^{-1}) = 4.55(0.12) − 0.70(0.03)*lnGM (g) ($n = 72$, $t = -21.40$, $p < 0.001$, $r_2 = 0.87$).

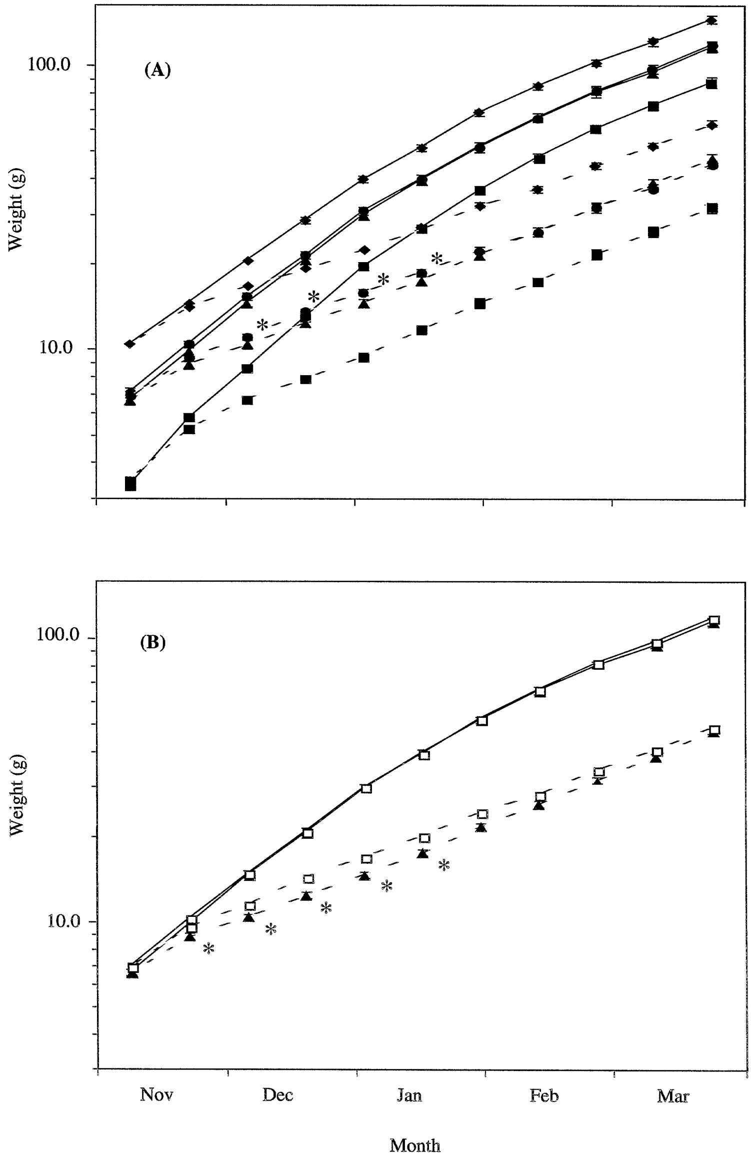

FIG. 1. Mean weights of four size-graded groups of juvenile turbot at two temperatures. The vertical line indicating standard error of mean (SE) may be obscured by the symbol. (A) All groups. Symbols: ▲, ungraded; ■, small; ●, medium; ◆, large. (B) Graded groups (small, medium, large) pooled plotted alongside with ungraded groups. Symbols: ▲, ungraded; □, small, medium and large pooled. * Indicates significant difference (Student–Newman–Keuls test, $p < 0.05$) between medium and ungraded groups (A) and between pooled and ungraded groups (B), within each temperature. Broken lines, 13 °C; solid lines, 19 °C.

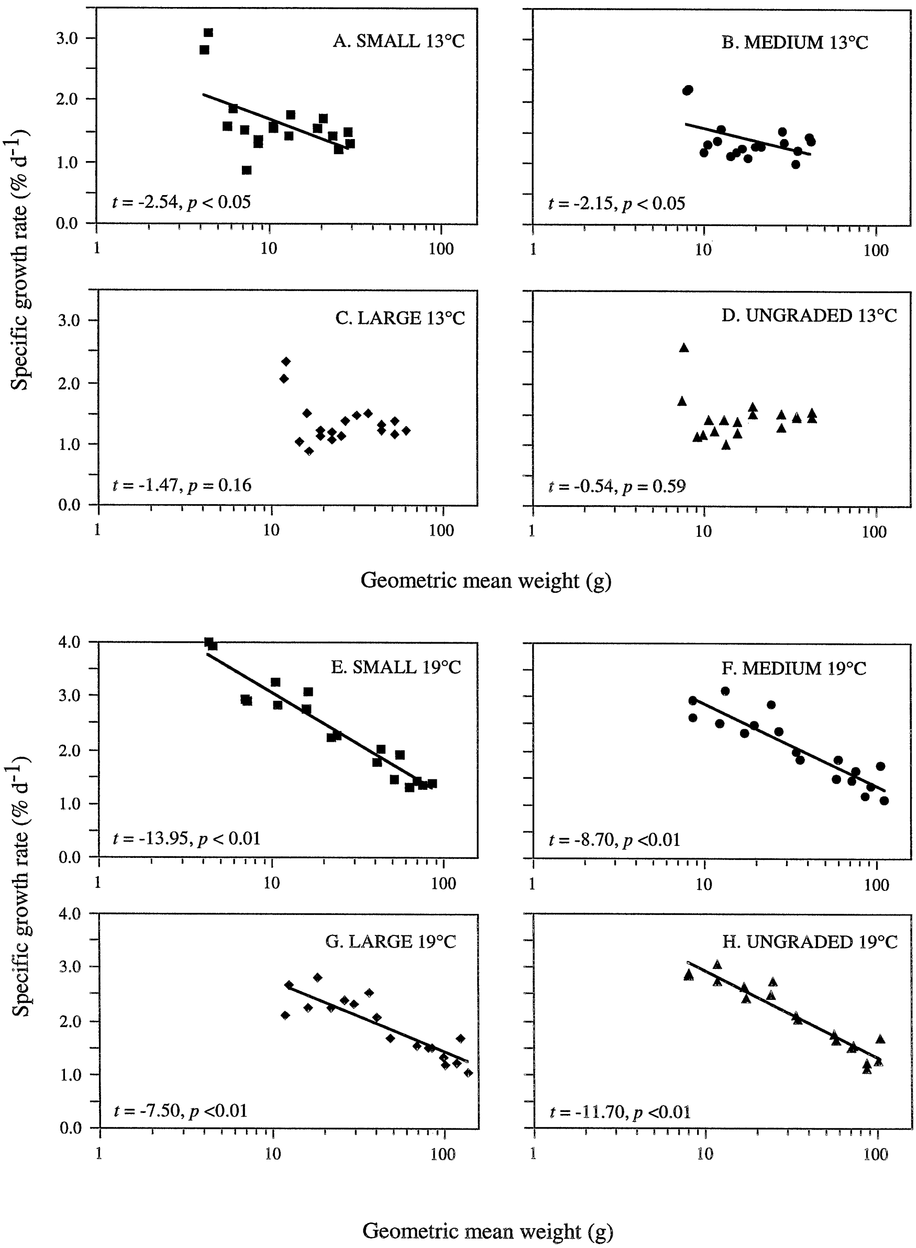

FIG. 2. Specific growth rates (*SGR*) in relation to geometric mean (*GM*) weight for size-graded groups of juvenile turbot reared at two temperatures. Each data point is the mean of 90–100 fish in a replicate tank. Symbols: ▲, ungraded; ■, small; ●, medium; ◆, large. The growth rates during the first 2 weeks after tagging were not included in these analyses. Regression lines are omitted in non-significant cases.

TABLE 2. Analysis of covariance (ANCOVA) for the regression of specific growth rate (*SGR*, % day^{-1}) against geometric mean (covariate = *GM*) weight (*W*, g wet weight) for the different grading groups (*G*); d.f. = degrees of freedom. Separate analyses were carried out for groups at 13 °C and 19 °C. Data for the first period after tagging were not included in the analyses

Temperature (°C)	Source of variation	Sum of squares	d.f.	Mean square	*F*-ratio	*p*
13	Main effect					
	Grading groups (*G*)	0.12	3	0.04	0.30	0.82
	Covariate					
	GM weight (*W*)	1.62	1	1.62	12.07	< 0.01
	Interaction					
	$G \times W$	0.43	3	0.14	1.07	0.37
	Residual	9.00	67	0.13		
19	Main effect					
	Grading groups (*G*)	0.006	3	0.002	0.03	0.99
	Covariate					
	GM weight (*W*)	27.22	1	27.22	403.93	< 0.01
	Interaction					
	$G \times W$	0.50	3	0.16	2.67	0.06
	Residual	4.51	67	0.07		

Size ranking and size distribution

There were significant relationships between the size ranking of the fish at tagging and at last weighing within all the groups at both temperatures (Spearman's rank correlation $r_S > 0.76$, $p < 0.001$). Maintenance of size rank did, however, differ between size categories. Size rank was more stable for the fish in the smallest (A) and the largest (D) categories than amongst fish in intermediate size (B and C, *Z*-test, $p < 0.05$).

Among the fish in the small, medium and large groups at both temperatures, the coefficient of variation (CV) of weight increased as the fish increased in weight (log regression, $p < 0.01$, Fig. 3). In the ungraded groups, on the other hand, CV either decreased slightly or remained unchanged (log regression, $p > 0.08$ and $p > 0.50$ for 13 °C and 19 °C, respectively, Fig. 3).

DISCUSSION

Size grading of juvenile turbot did not result in improved growth in the present experiment, and the relative position of the small and large groups did not change within each temperature (Fig. 1). One might have expected better growth in the medium groups compared with the ungraded groups as there was a greater size variance in the latter, with possible negative effects of social interactions (Jobling, 1982; Knights, 1987). However, there were no differences in growth between the medium-sized and ungraded groups. This provides a further indication that grading does not improve growth of juvenile turbot. Similar results have been found for Arctic charr, *Salvelinus alpinus* (Wallace and Kolbeinshavn, 1988; Baardvik and Jobling, 1990), cod, *Gadus morhua* (M. Jobling, unpublished results) and eel, *Anguilla*

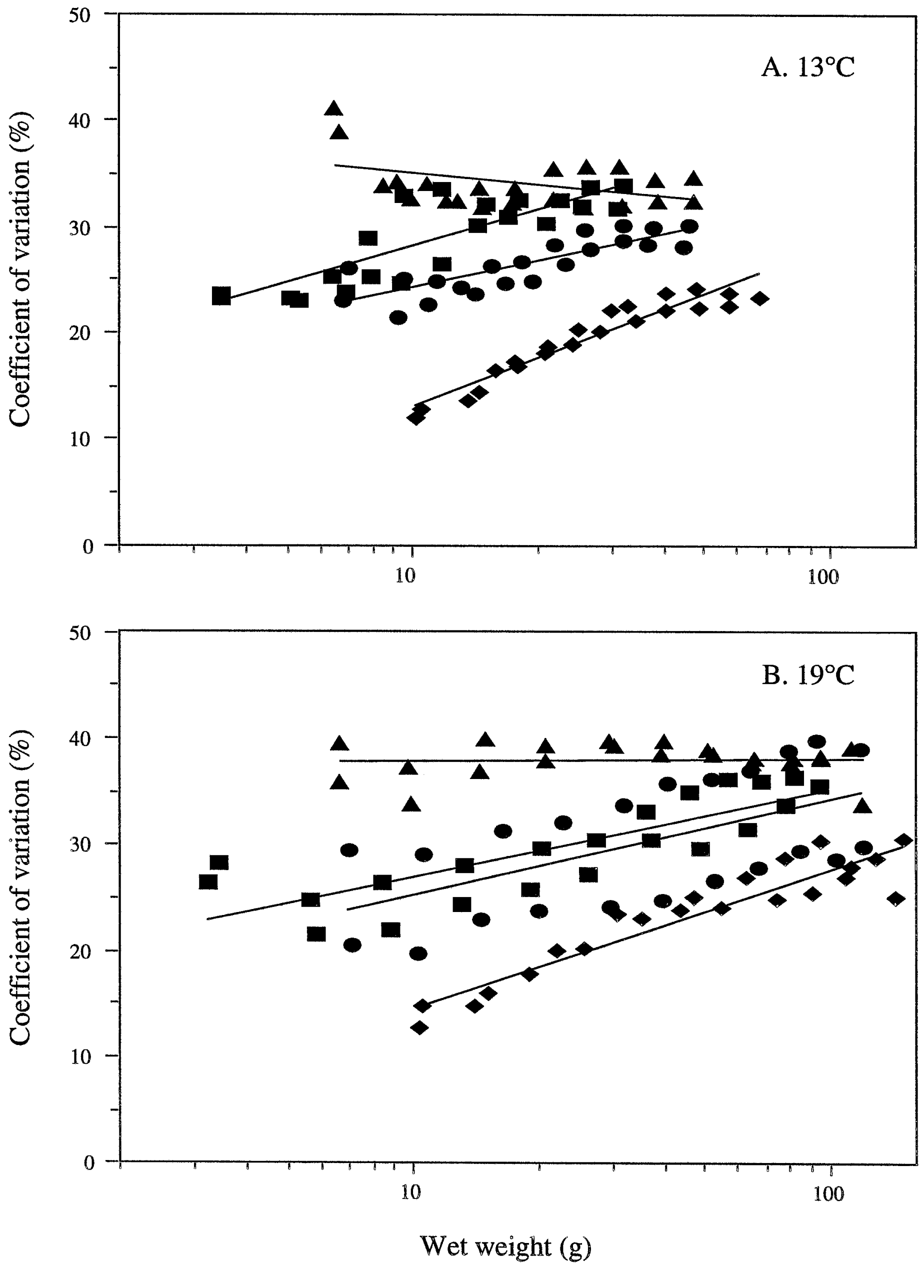

FIG. 3. Coefficient of variation (weight, %) plotted against wet weight (g) for four size-graded groups of juvenile turbot at two temperature regimes: A, 13 °C; B, 19 °C. Symbols: ▲, ungraded; ■, small; ●, medium; ◆, large. Lines indicate log-regression of the data.

anguilla (Kamstra, 1993), whereas size grading has been shown to result in improved growth of juvenile Atlantic salmon, *Salmo salar* (Gunnes, 1976), gilthead sea bream, *Sparus auratus* (Popper *et al.*, 1992), and Nile tilapia, *Oreochromis niloticus* (Brzeski and Doyle, 1995).

Although the small fish had higher *SGR*s (individual growth-at-age trajectories) than the large fish during the latter stages of the experiment, this difference could be explained on the basis of size-specific growth. Thus, grading by size did not improve growth at any given size (Fig. 2, Table 2), a finding that is at odds with the main purpose of grading, i.e. to achieve better growth of small individuals by separating them from larger individuals. Some authors have shown that intra-specific competition and agonistic interaction is greater when fish of similar size are reared together (Doyle and Talbot, 1986; Baardvik and Jobling, 1990). This indicates that a greater size variation does not necessarily lead to a higher degree of social interactions, and result in reduced growth. Once corrections for body size were made, the juvenile turbot in the small groups were found to grow equally as well as fish in the other grading groups, indicating that explanations other than low growth potential were the reason why these individuals were smaller initially. Chambers and Leggett (1992) analysed the effects of size and age at metamorphosis on the size variation in juvenile flatfish, and concluded that age at metamorphosis was an important factor influencing size distributions. The juveniles used in the present study were the offspring of one female and two males and metamorphosis occurred over a period of approximately 4 weeks. It is, therefore, possible that the initial size variation seen in the present study is to some degree an effect of different metamorphic age in the fish material used.

Feeding every 6 min and feeding in excess may have been important factors in reducing aggression, so that the growth of the smallest individuals was not suppressed by the larger individuals in the present study. Jobling and Koskela (1996) analysed interindividual variations in growth in rainbow trout *Oncorhynchus mykiss*) during restricted feeding and in a subsequent period of full feeding, and suggested that feeding hierarchies were established under feed restriction but were rapidly broken down under full feeding.

The survival rates of around 97% in the present study were similar to those observed in earlier studies on juvenile turbot (Purdom *et al.*, 1972; Heap and Thorpe, 1987; Person-Le Ruyet *et al.*, 1991; Gaumet, 1994). An *Aeromonas* sp. infection was detected but mortality remained low, indicating that juvenile turbot > 5 g are robust enough to tolerate frequent handling (e.g. weighing), although mortality tended to be a little higher amongst the smaller fish (Table 1). None of the dead fish bore signs of aggressive behaviour (e.g. bite marks). This contrasts with the findings of Smith (1979), who reported that all mortality within a group of wild-caught juveniles (1.3–3.7 g) was due to aggression, and that it was the smallest individuals that had bite-marks or other signs of agonistic acts. The absence of mortality owing to aggression in the present study is, however, in line with the observation of Hull and Edwards (1979): They compared wild-caught and hatchery-reared fish and found signs of aggression only in the wild fish. Thus, it is possible that hatchery-reared fish (this study) are more tolerant than wild fish.

Size variation (CV) increased with increased size of fish in the small, medium and large groups at both temperatures (Fig. 3), whereas CV was stable (19 °C) or decreased (13 °C) in the ungraded groups. Size distributions of graded groups have previously been reported to increase to the same level as in ungraded groups as time progressed, with such findings being reported for turbot (Purdom *et al.*, 1972), juvenile cod (Folkvord and Otterå, 1993), and channel catfish, *Ictalurus punctatus* (Carmichael, 1994). Amongst groups of juvenile eel (Wickins, 1985) and Arctic charr (Wallace and Kolbeinshavn, 1988), CV has been found to increase in groups of small fish but remain unchanged when groups were established using fish representing the larger classes of the size-frequency distribution. The increase in CV observed in the present study amongst the small, medium and large groups might suggest competition or hierarchical effects among juvenile turbot because in populations where the growth of some individuals is suppressed by competition, CV increases (Jobling, 1982).

Alternatively, the changes in size distribution in the present study may have originated from inherent genetic differences in growth capacity of the fish. The fact that size rank was relatively constant in all groups, although CV of weight increased with size, may indicate genetic control of observed growth-at-age trajectories (Huston and DeAngelis, 1987). Heritable differences in growth capacity and growth pattern lead to changes in size distribution (Magnuson, 1962; Huston and DeAngelis, 1987), and variation in growth in the absence of social interactions between individuals of different size has been reported earlier for eel (Wickins, 1985). Doyle and Talbot (1986) hypothesized that size CV in fish was not necessarily due to social interactions but rather was a consequence of differences in metabolism, activity and utilization of food resources. Some recent studies have reported genotypic-specific catabolic and anabolic activity (Kramer *et al.*, 1992; Crivello and Schultz, 1995), and genotypic-specific growth and oxygen affinity (Imsland *et al.*, 1997). Large individual growth differences for turbot at a given size have been reported in earlier studies (Jones, 1973; Gaumet, 1994; Nijhof, 1994), indicating that growth capacity could to some extent be a heritable trait in turbot.

CONCLUSIONS AND RECOMMENDATIONS

1. Size grading of juvenile turbot did not lead to improved growth. Smaller individuals grew equally as well when reared together with larger individuals (ungraded) as they did in the absence of larger individuals (size graded).
2. Grading does not seem to be necessary to improve the survival of juvenile turbot.
3. The decline in growth (*SGR*) with the passage of time was a size-related effect; grading by size did not improve growth at any given size for any of the experimental groups.
4. Frequent and excess feeding may have been important factors in reducing aggression, so that the growth of the smallest individuals was not suppressed by the larger individuals in the present study.

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